Available online at www.sciencedirect.com
ScienceDirect
Physics Procedia 9 (2010) 216–220
Physics Procedia
www.elsevier.com/locate/procedia

12th International Conference on Magnetic Fluids

Bubbles generation mechanism in magnetic fluid and its control by an applied magnetic field

Floriana D. Stoian[a,]*, Sorin Holotescu[a], Ladislau Vékás[b]

[a] Faculty of Mechanical Engineering, "Politehnica" University of Timisoara, 1 Mihai Viteazu Bv., Timisoara 300222, Romania
[b] Laboratory of Magnetic Fluids, Romanian Academy – Timisoara Division, 24 Mihai Viteazu Bv., Timisoara 300223, Romania

Abstract

A comparison of the effect of an applied magnetic field on the bubble departure diameter in a magnetic nanofluid, for different orientations of the magnetic field gradient with respect to gravity, is presented. Using the instantaneous relative pressure during the bubble growth and departure and the instantaneous gas flow rate measured for a certain range of magnetic field intensity, the dependence between the average bubbles injection frequency, average bubble volume and the applied magnetic field were studied. An effect of the injection hole size on the bubble frequency was observed.

Keywords: bubble departure diameter; magnetic nanofluid; nucleate boiling; magnetic field.

1. Introduction

Heat dissipated in various types of devices and equipments that nowadays are getting more and more compact, surpasses the heat transfer performances of conventional cooling fluids. If we consider of combining the most promising passive method, that is the use of nanofluids as cooling fluid, with an active method – application of external fields, which can give the possibility of controlling the enhancement rate, than a solution could be offered by the magnetic nanofluids and an external magnetic field.

Boiling heat transfer is characterized by the highest heat transfer coefficients. Among the characteristic parameters of boiling, the average equivalent bubble diameter (assuming the bubble as a sphere, of an average size) is of major importance for the theoretical study of the nucleate boiling heat transfer but due to the parameters that influence the bubble formation and departure it is difficult to determine it theoretically [1]. Boiling of magnetic nanofluids was studied experimentally and theoretically, both from the point of view of enhancement rate and mechanisms [e.g. 2,3].

* Corresponding author. Tel.: +40 744 597308; fax: +40 256 403700.
E-mail address: floriana.stoian@mec.upt.ro (F.D. Stoian).

doi:10.1016/j.phpro.2010.11.048

The results of an experimental study regarding the bubble generation frequency and the bubble equivalent average diameter, as a function of the applied magnetic field, are presented in this work.

2. Theoretical background

The condition of bubble departure from the surface can be determined from the force balance on the vapor bubble during the process of growing. The simplest equation for the bubble departure diameter, D_r, includes the buoyancy and surface tension forces:

$$D_r = f(\beta)[\sigma/g(\rho_L - \rho_G)]^{1/2} \quad (1)$$

where $f(\beta)$ is the liquid to surface contact angle, σ – the surface tension, ρ_L – the liquid density, ρ_G – the vapor density, g – gravitational acceleration. This equation does not include the effects of inertia and drag forces, like more recent and complex ones [1]. In the case of boiling of a magnetic nanofluid in the presence of an external magnetic field, the magnetic body force that acts on the growing bubble must be added in the force balance:

$$\vec{F}_m = -\mu_0 VM(H) \cdot \nabla H \quad (2)$$

where μ_0 – free space permeability, V – bubble volume, M – magnetic fluid magnetization, H – magnetic field intensity. Thus, if the inertia and drag forces are neglected, the force balance results in [4]:

$$\vec{F}_b + \vec{F}_m = \vec{F}_s \quad (3)$$

when buoyancy force and magnetic force act in the same direction. In this case the bubble departure diameter is:

$$D_{r,m} = f(\beta)\sqrt{\sigma/(\rho_L - \rho_G)g \pm \mu_0 M\nabla H} \quad (4)$$

the sign is depending on the relative orientation of buoyancy force and magnetic force.

3. Experimental bench

The experimental bench, presented in Fig.1, was designed to study the phenomena related to the growth and departure of bubbles injected from a flat surface in magnetic fluid and the effects of an applied magnetic field. A non-uniform magnetic field is generated using profiled, V-shaped, electromagnetic poles, which give rise to a constant gradient of the magnetic field, ∇H, parallel with the gravitational field, $\vec{g}$, with the same orientation as $\vec{g}$, or opposite orientation to $\vec{g}$, if the V-shaped poles are switched up-side-down. Prior to actual experiments, the magnetic flux density was measured along the symmetry axis of the air gap, with a 10 mm step. The field measurement was carried out using a Hall probe (6) and Bell Gaussmeter (5). The resulted field gradient at the hole site (50 mm up from the bottom of the poles) was 79.6 kA/m^2.

The experimental cell (9) is a cylinder with glass walls (Φ_{ext} = 38 mm and wall thickness 3 mm) and plexiglass bottom cap. The level of magnetic fluid in the cell was 55 mm. The injection hole was drilled in the center of the bottom cap. Three cells, with different hole diameters, d, of 0.3, 0.7 and 1.5 mm, were tested.

The magnetic nanofluid sample was a colloidal suspension of magnetite nanoparticles dispersed in hydrocarbon oil (TR-30), with density 1470 kg/m^3. The magnetization of the fluid sample was measured using a VSM magnetometer (DMS/ADE Technology, USA), the saturation value being 44.747 kA/m.

Using the experimental procedure described in [5], we measured the instantaneous relative pressure during the bubble growth and departure, close to the injection hole, and the injected gas flow rate.

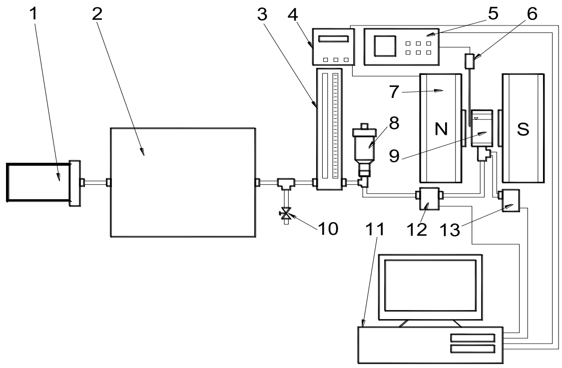

Fig.1: 1 – compressor; 2 –gas reservoir; 3 – manometer; 4 – magnets power supply; 5 -gaussmeter; 6 – Hall probe; 7 – magnetic poles; 8 - micrometer valve; 9 – experimental cell; 10 – flow rate valve; 11 – PC computer with data acquisition system; 12 - flow rate transducer; 13 – pressure transducer

The relative pressure was measured with a differential pressure transducer, accuracy ± 1 %. A flow rate sensor, accuracy ± 1 %, measured the injected gas flow rate. All data were recorded using a computer equipped with a NI DAQ system using the LabView software. By measuring the time period between two peaks we get the bubble emission period, τ_b, and then the bubble frequency, *f*. By averaging the value of the measured flow rate over the acquisition period, we get the average gas flow rate. The average bubble volume, V_b, and further, the equivalent bubble diameter (of an equivalent spherical bubble of volume equal to V_b), D_{ech}, are obtained.

4. Results and discussion

The experiments showed that the applied magnetic field is influencing the bubble generation frequency, as well as the average equivalent bubble diameter. For the injection hole d = 1.5 mm, the average frequency is increasing with the applied field when the field gradient has the same orientation as gravity and if the orientation is reversed, the frequency is decreasing. The values plotted in Fig.2 show the variation of *f* from approximately -25% to + 55%, taking as reference the bubble generation frequency at zero field. The dependences obtained for the average equivalent diameter in the same case are presented in Fig.3. For the investigated field range, D_{ech} ranged from -16 % to + 12 % of the reference value at zero applied field. Results reported by Bashtovoi et al [6], using a magnetic nanofluid of similar composition and saturation magnetisation, and capillary tubes of 0.8 to 1.8 mm diameter, showed that by applying a much higher field gradient, of different values and about 10 times higher than in this experiment, a corresponding much higher variation of the bubble volume can be obtained.

However, if the injection hole diameter was decreased, the case of d = 0.7 mm and d = 0.3 mm, the bubble generation frequency followed the ascending trend only to a certain magnetic field, after which the bubble generation frequency started to decrease, as shown in Fig.4. A possible explanation could be that from a certain value of the applied field inertia and drag forces have to be accounted for, as the bubble departure diameter lowers. Also, the characteristic times of the phenomena may play a role. Nucleate boiling experiments of a kerosene based magnetic fluid [7] in uniform field showed a similar trend, by increasing the boiling fluid temperature and the applied magnetic field, the bubble generation frequency increases at first and then decreases.

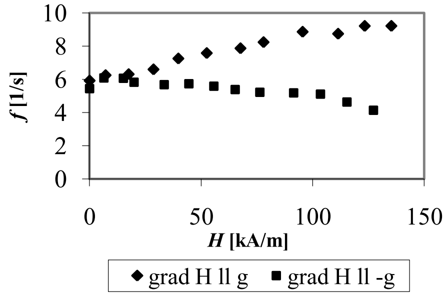

Fig.2. Average bubble generation frequency as a function of the applied magnetic field and its gradient orientation, d = 1.5 mm

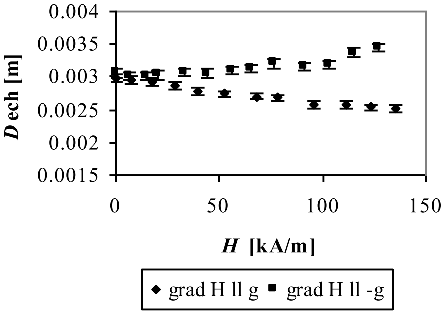

Fig.3. Average equivalent bubble diameter as a function of the applied magnetic field and its gradient orientation, d = 1.5 mm

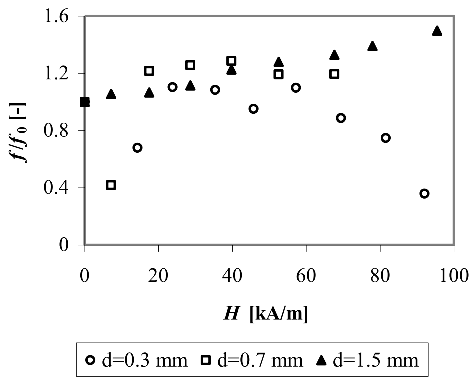

Fig.4. Bubble generation frequency as a function of the diameter of the injection hole, for grad H ll g

5. Conclusions

The experimental results showed that the bubble departure diameter and bubble frequency are influenced by the magnetic field, according to the force balance accounting for surface tension, buoyancy and magnetic force. Also, it was observed that the injection hole size might affect the bubble frequency and, consequently the bubble departure diameter, in correlation with the applied field.

Acknowledgement

The financial support of the Romanian Space Agency (ROSA), Grant No. 37/2001-2004, for the start-up of this research is acknowledged.

References

[1] A. Bejan, A.D. Kraus, Heat Transfer Handbook, Wiley-Interscience, 2003.
[2] M. Takahashi, K. Shinbo, R. Ohkawa, M. Matsuzaki, A. Inoue, J. Magn. Magn. Mater. 122 (1993) 301-304.
[3] B.Jeyadevan, H. Koganezawa, K. Nakatsuka, J. Magn. Magn. Mater. 289 (2005) 253-256
[4] E. Blums, A. Cebers, M.Maiorov, Magnetic fluids, Walter de Gruyter, Berlin, New York, 1997.
[5] F.D. Stoian, Gh.Pop, D. Bica, V. Stoica, O. Marinica, L. Vékás, Proceedings 3rd Int. Symp. Two-Phase Flow Model. Exp. Pisa, Italy, Vol. 3 (2004), 971-978.
[6] V. Bashtovoi, M. Kovalev, A. Reks, J. Magn. Magn. Mater. 289 (2005) 382-384.
[7] M. A. Kobozev, A.Ya. Simonovschii, Technical Physics 52 (2007) 1422-1428.